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ABSTRACT

This second in a series of six modules for a course titled Nondestructive Examination (NDE) II describes specific ultrasonic test techniques and calibration principles. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

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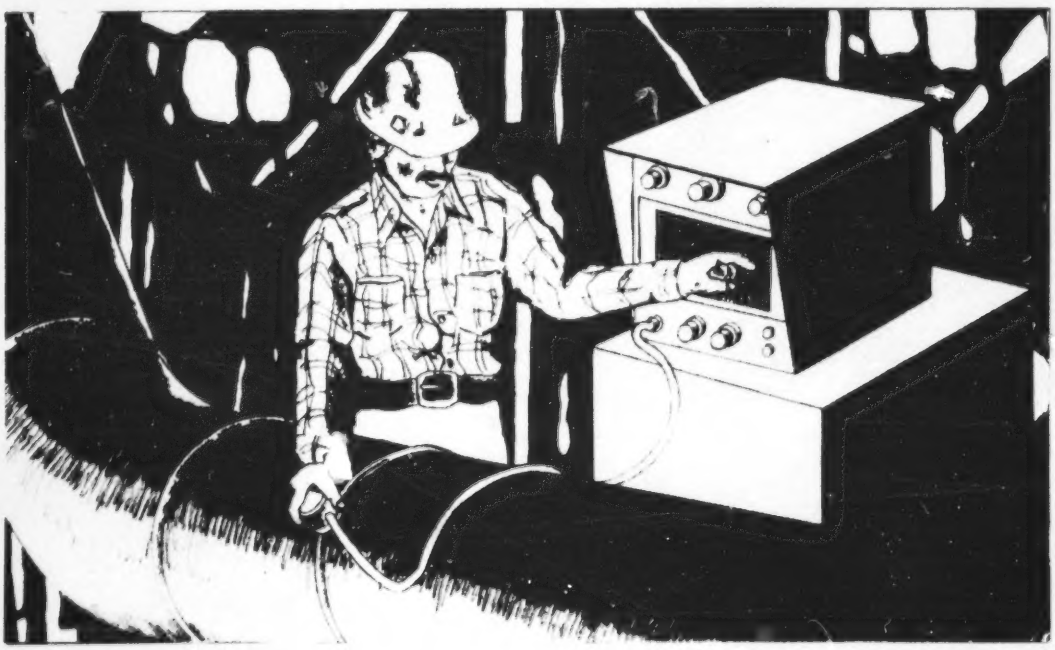
NUCLEAR TECHNOLOGY

COURSE 32 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES II

MODULE 32-2 Operation of Ultrasonic Test Equipment



CE 024 294

GENERAL PHYSICS CORPORATION
Columbia , Maryland

COURSE MODULES

COURSE 32 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES II

Module 32-1 Fundamentals of Ultrasonic Testing
Module 32-2 Operation of Ultrasonic Test Equipment
Module 32-3 Fundamentals of Magnetic Particle Testing
Module 32-4 Operation of Magnetic Particle Test Equipment
Module 32-5 Fundamentals of Eddy Current Testing
Module 32-6 Operation of Eddy Current Test Equipment

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This module was prepared for General Physics Corporation by John Espy of General Physics Corporation.

GENERAL PHYSICS CORPORATION

1979

INTRODUCTION

The Nuclear QA/QC Technician may have several responsibilities for ultrasonic examinations. The technician may serve as an ultrasonic test inspector. Also, the technician may assist in reviews and audits of ultrasonic test reports and practices by other organizations.

Ultrasonic testing is widely used in the nuclear industry. It is a volumetric test which examines the volume of materials and welds. It is mostly used for the examination of base metals by material fabricators and for in-service inspections of welds by the nuclear power plant operator. In these uses, the pulse-echo method is used almost without exception. Both contact and immersion techniques are used. A-scan is mostly used with contact method and A-scan or C-scan is used with immersion method. This module describes specific ultrasonic test techniques and calibration principles associated with these tests.

MODULE PREREQUISITES

The student/trainee should have prior training or experience in fundamentals of ultrasonic testing. Completion of Nuclear Technology Module 32-1, Fundamentals of Ultrasonic Testing, satisfies this prerequisite.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Compare single and double transducers.
2. Differentiate longitudinal and shear wave techniques.
3. Calculate critical angles and angles of incidence with respect to angle beam testing.
4. Plot angle beam scanning paths for given test specimens.
5. Describe the surface wave technique.
6. Differentiate contact and immersion techniques.
7. Briefly describe squirter, bubbler, and wheel techniques.
8. Discuss the factors associated with selection of search units.
9. Recognize ASME, ASTM, and IIW calibration reference blocks.
10. Describe and perform linearity calibration.
11. Describe and perform sweep range calibration.
12. Describe and perform distance amplitude calibration.
13. Relate minimum detectable flow size and test frequency.
14. Describe and demonstrate techniques for determining flow position, depth and size.
15. Describe effects of grain size and acoustic velocity variables on ultrasonic testing.

ULTRASONIC TEST TECHNIQUES

Types of Techniques

There are four classes of methods available to the ultrasonic technician. Of these, there is one class that is widely used. This is the intensity and transit time (ITT) method. The most commonly required type of ITT method by governing codes is the pulse-echo method.

The pulse-echo method is generally conducted by two means: contact testing and immersion testing. In most contact tests the probes are generally hand held and manually swept over the search area. A couplant is virtually always required. Immersion testing is generally automated and typically uses water, oil, or glycerin as couplant.

Two general categories of contact testing exist: straight beam testing and angle beam testing. Straight beam testing uses longitudinal waves whereas angle beam testing uses shear waves (transverse waves). When the shape of the test piece prevents straight access to the region or volume of interest, the angle beam method, is used. Angle beam transverse testing is also the type used to produce surface waves at the S-wave critical angle.

Straight Beam Contact Techniques

Pulse-echo contact testing using straight beams typically employs the A-scan method. Single or double transducers may be used. The single transducer technique is most useful when testing smooth parallel surfaces. The double transducer or pitch-catch technique is useful for a rough or inclined back surface. Another use for the double transducer method is to isolate electrically the pulser and receiver-amplifier. This prevents the pulser from saturating the receiver-amplifier with the transmitted pulse, thereby

avoiding the dead or recovery time after that initial pulse. This improves the resolution of the instrument with respect to discontinuities near the surface of the test piece.

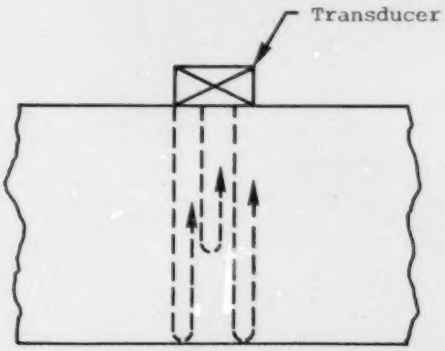

Figure 32-2-1 Single-Transducer Technique

If two transducers are used in the examination of a test piece, one additional advantage accrues to the examiner. The transmitting and receiving transducers may be constructed of different materials that closely match the function of each transducer. For example, the transmitter might be composed of barium titanate and the receiver of lithium sulfate.

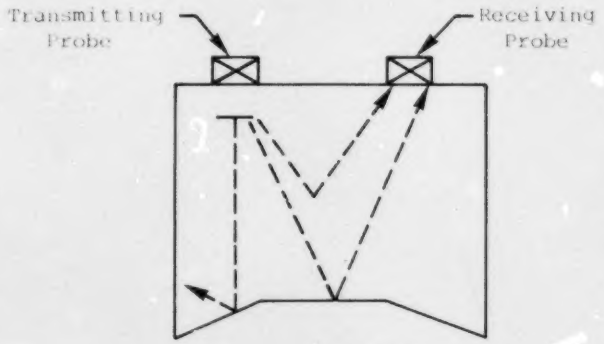

Figure 32-2-2 Double-Transducer or Pitch-Catch Technique

Angle Beam Technique

The angle-beam contact technique is used to transmit ultrasonic transverse waves into the test sample. Since it is desirable to avoid mixed modes, this technique almost invariably uses transverse or shear waves with a contact angle between the first and second critical angles. This will cause the longitudinal waves to be totally reflected at the interface and only the transverse waves are propagated in the test piece.

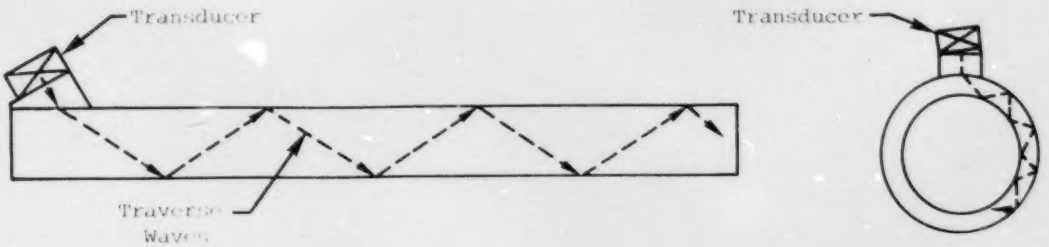

Figure 32-2-3 Angle Beam Techniques

The contact angle is obtained by use of a rigid, wedge-shaped adaptor. In order to operate between the critical angles it is necessary to have a material for the wedge with a lower velocity of sound than in the test substance. And since there is mode conversion, the longitudinal velocity in the adaptor must be smaller than the transverse velocity in the test substance. When testing aluminum or steel, therefore, a longitudinal velocity of less than 3000 $\frac{m}{sec}$ or 3 $\frac{km}{sec}$ is highly desirable in the adaptor. Lucite, with $C_l = 2.7 \frac{km}{sec}$, is ideal.

EXAMPLE: 32-2-1

Problem: What are the two critical angles for a lucite to steel interface?

Given: steel: $C_l = 5.9 \frac{km}{sec}$ $C_t = 3.2 \frac{km}{sec}$

Lucite: $C_l = 2.7 \frac{km}{sec}$

Solution: $\theta c_1 = \sin^{-1} \frac{C_{lp}}{C_{lst}} = \sin^{-1} 0.46 = \underline{\underline{27^o}}$

$\theta c_2 = \sin^{-1} \frac{C_{lp}}{C_{lst}} = \sin^{-1} 0.84 = \underline{\underline{57^o}}$

EXAMPLE: 32-2-2

Problem: What angle of incidence in lucite produces a 45^o angle in steel for transverse waves?

Given: ($C_e = 2.7 \frac{km}{sec}$) lucite, ($C_t = 3.2 \frac{km}{sec}$) steel

Solution: $\frac{\sin \theta_l}{\sin \theta_{st}} = \frac{C_l}{C_{st}}$

$\sin \theta_l = (\frac{2.7}{3.2}) \sin 45^o = 0.84 \times 0.71 = 0.60$

$\theta_l = 36.6 \approx 37^o$

Angle probes with lucite adaptors are pre-calibrated for the angle of refraction into steel. Care should be taken to account for the change of angles due to different sound velocities in other materials, such as aluminum or copper.

When locating a flaw or discontinuity by the angle beam method, one must normally examine some particular plane of interest in the sample. To complete such an examination, the transducer must be moved from the distance 2L to the distance L from the plane of interest. This will permit the beam to transverse the plane completely, as can be seen in Figure 32-2-4. The distance 2L is referred to as the skip distance or a V-path length.

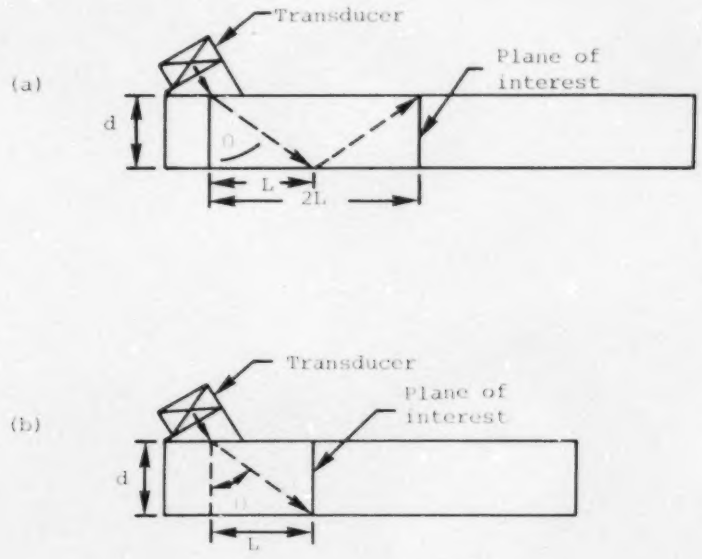

Figure 32-2-4 Angle Beam Technique

By simple trigonometry L can be computed, given d and θ:

$$L = d \tan \theta \qquad \text{Equation 32-2-1}$$

Where

L - ½ skip distance

d = test material thickness

θ = entry angle

In addition to checking the thickness direction of the test piece, the test pattern must sweep the width of the test piece. These two patterns can be combined to produce a zig-zag search or scanning pattern as shown in Figure 32-2-5. The boundary marks for the scanning pattern are established by the value of L as calculated by equation 32-2-1. The boundary marks and scanning pattern assure coverage of the entire weld volume by the angle beam technique.

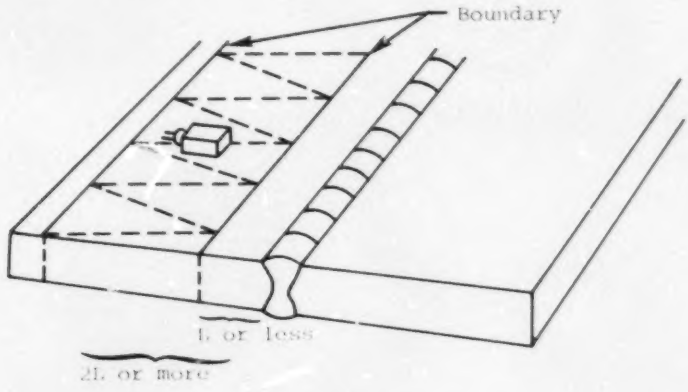

Figure 32-2-5 Scanning Path for Angle Beam Examination of a Weld

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Surface Wave Contact Technique

A special case of angle beam testing occurs when the angle of incidence equals the second (or S-wave) critical angle. The mode conversion to transverse waves at the interface then produces surface or Rayleigh waves which then propagate along the surface. These surface waves will follow the surface around the curves, excepting, of course, sharp corners. The surface wave technique is most useful in locating flaws which extend to the surface or are in the dead-zone or near-field for other techniques. Figure 32-2-6 shows an example of surface wave technique

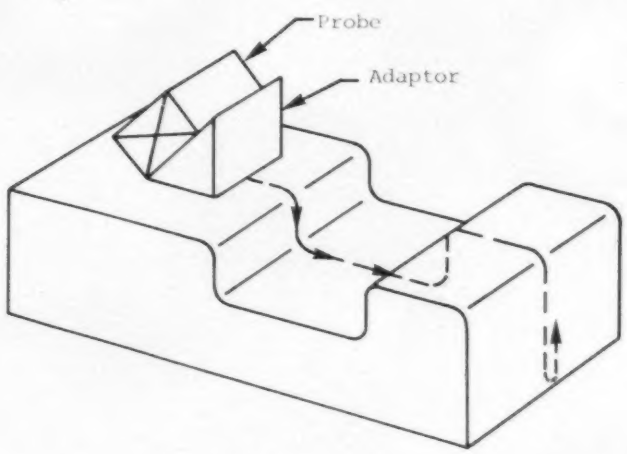


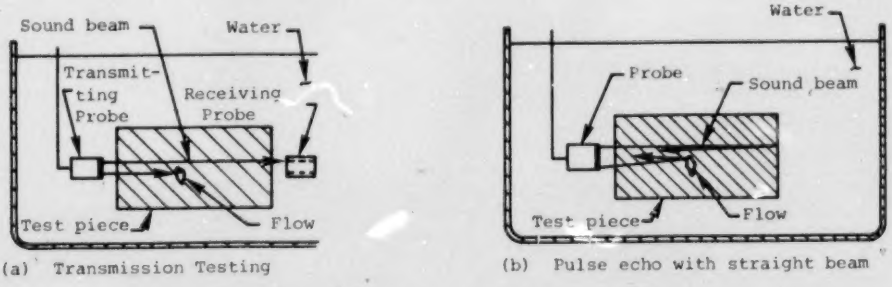
Figure 32-2-6 Surface-Wave Technique

Immersion Testing

The immersion method of ultrasonic testing consists of three basic techniques: the immersed technique where both the transducer and the test specimen are under couplant; the bubbler or squirter technique where the ultrasound is transmitted in a column of flowing water; and the wheel scanning technique where the transducer is immersed in a water-filled rubber tire. As in contact testing, the pulse-echo method is most commonly used.

Immersed Technique

In the immersed or conventional immersion technique, both the probe and the test piece are immersed in couplant. Water is frequently used as the couplant for this technique. Immersion probes are essentially waterproof straight beam units with angle-beam inspection being accomplished by merely changing the position of the probe to various angles with respect to the front surface of the test part. Such a procedure is referred to as angulation.



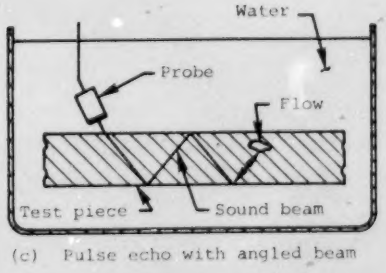


Figure 32-2-7 Conventional Immersion Techniques

As a rule, the conventional immersion technique is accomplished by automated or semi-automated mechanical scanning, as opposed to the manual scanning used in contact testing. Since the various bridge-manipulators in use allow for controlled planar scanning, the conventional immersion

technique using an X-Y plotter is the preferred method for C-scans. A typical universal immersion scanner is shown in Figure 32-2-8.

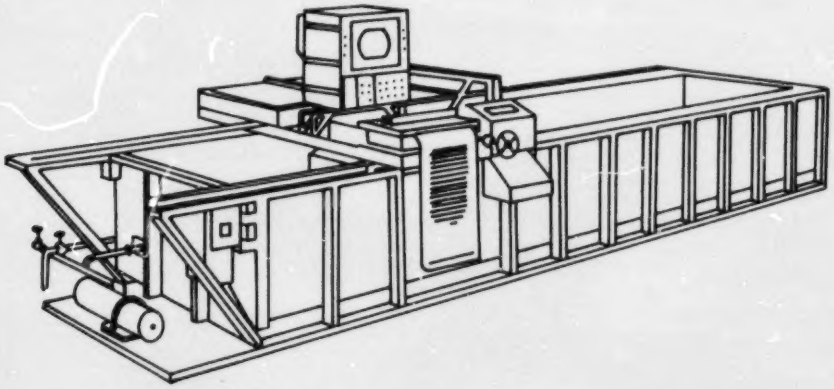


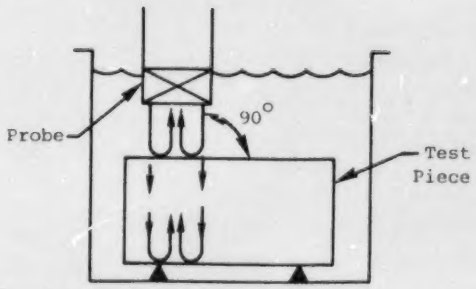
Figure 32-2-8 Sample Immersion Test Equipment

In the immersed technique, there are one or more extra echoes on an A-scan presentation, in addition to the initial pulse. These additional echoes are due to multiple front surface and probe reflections. To eliminate multiple front surface echoes, the acoustical path length in the water. should take longer to traverse than the acoustical path length in the test piece.

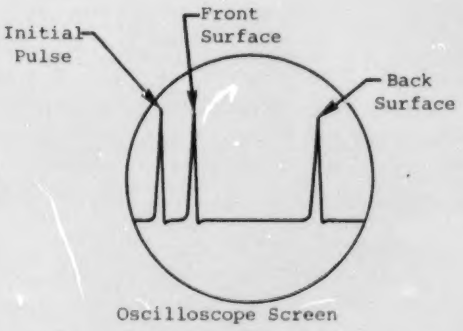
To ensure that this is the case, it is necessary to compare the velocity of sound in water to that of the test piece, which may be typically steel or aluminum. The velocity of sound in steel or aluminum is more than four times the velocity of sound in water. Therefore a water path length of one-fourth the thickness of the steel or aluminum test piece is adequate. As a result, a widely used "rule-of-thumb" has been established in this regard which cites that:

The water thickness employed for the immersed technique shall be one-fourth of the specimen thickness plus a quarter of an inch.

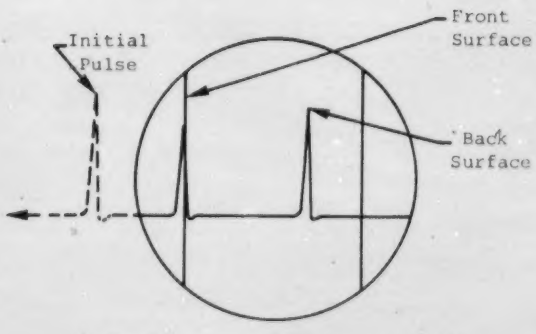
The A-scan immersion test is illustrated in Figure 32-2-9.



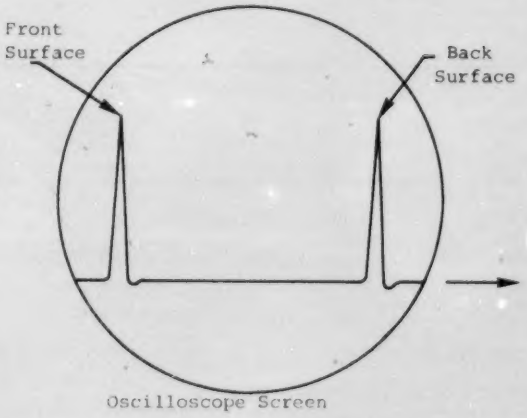
(a) Straight-beam, pulse-echo immersion test set-up



(b) Initial CRT display



(c) CRT display with sweep delay correction to disregard the water path length.



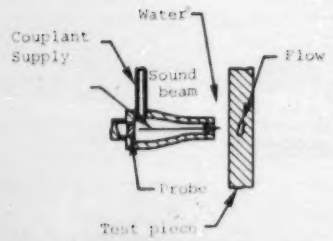
(d) CRT display with sweep correction to display thickness over full scale.

Figure 32-2-9 Straight Beam, Pulse-Echo, Immersion Test

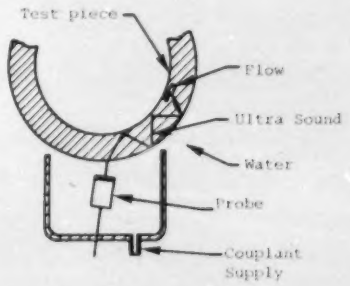
Because the thickness of the test piece is represented by the spacing between the front surface and back wall echoes, the front surface echo should be placed at the left-hand index using the sweep delay control. The initial pulse should now be off screen. Once that has been accomplished, the sweep control can be used to position the back wall echo to the right-hand most index marker as in Figure 32-2-9(d). This last step and succeeding steps are similar to the contact pulse echo method discussed in the proceeding module and in greater detail later in this module.

Water-Column Technique

The water-column technique is known as either the bubbler or the squirter method, depending on the shape and size of the water column. In the squirter technique, Figure 32-2-10(a), the water column gives a more directional flow of the coupling liquid than the bubbler technique, Figure 32-2-10(b).



(a) Squirter techniques, pulse echo method.



(b) Bubbler Technique, pulse echo method

Figure 32-2-10 Basic Water-Column Techniques

The water column techniques can be used as both straight and angle-beam techniques; only the orientation of the probe needs to be changed. The squirter technique can be used as a thorough-transmission technique by using a second squirter assembly on the back surface with a receiving transducer. Water-column techniques are used when the size or shape of a test piece does not lend itself to a submersion in a conventional test tank. As a general rule, large but regularly-shaped test pieces are examined by a squirter technique, while irregularly shaped test pieces are examined by a bubbler assembly.

Wheel Techniques

Wheel techniques are classified as immersion techniques even though the test pieces never get wet. An immersion probe is mounted inside a liquid-filled wheel and the ultrasound travels to the test piece through the liquid. The wheel type probe may also be used for straight or angle-beam testing, and frequently the only adjustment necessary is to tilt the mounting frame.

Wheel type units may be manipulated across the test piece, or held fixed as the test piece is drawn past it. Figure 32-2-11 shows schematic details of wheel-probe operations.

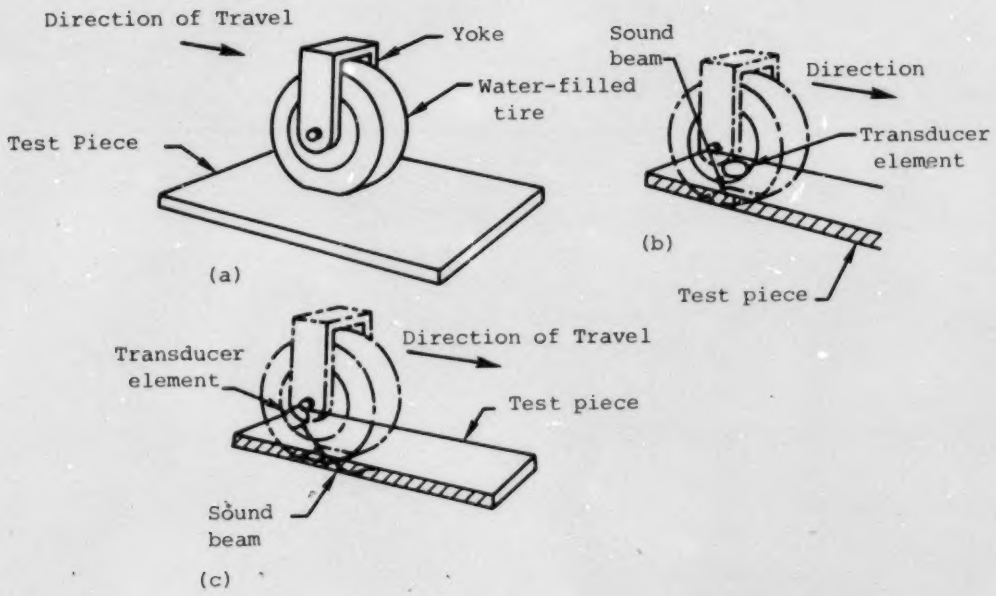


Figure 32-2-11 Immersion Testing by Wheel Probe

TYPICAL TEST TECHNIQUES AND RESULT INTERPRETATION

This section of the module describes specific techniques of ultrasonic testing and how to interpret the results obtained. Since virtually all nuclear ultrasonic examination is specified to be done by the pulse-echo method, all tests discussed below are pulse-echo techniques.

Pro[illegible]s and Probe Section

When undertaking a pulse-echo examination of a test piece, the optimum test parameters are determined by the configuration and composition of the material. These parameters include type (angle or straight) of test, frequency, coupling conditions, and temperature.

In nuclear NDE testing, the applicable written test procedure dictates straight-beam or angle-beam, and if angle-beam, it generally requires the effective angle in steel to be 45^{o}, although 60^{o} is sometimes required. The type of the technique, which is predetermined for the technician, determines the type of probe to be used.

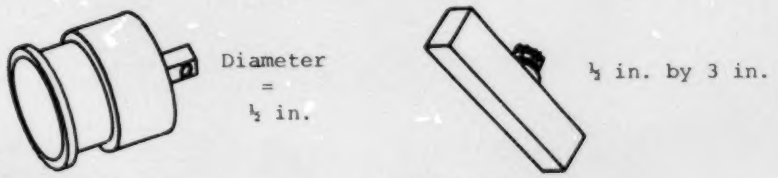
Today, most angle beam probes are supplied as separate transducer and adapter wedges. The reason is to reduce the cost of probes. As a result, a single transducer can be mated to any of several adaptors. Also, as adaptors wear out, it is much cheaper to replace the adaptor than an entire encapsulated search unit.

Four decisions about the probe must be made: frequency, size of probe, operating temperature, and shape or curvature of the face of the probe.

The optimum frequency for examination is selected by balancing the reduction of attenuation as frequency is reduced against the accompanying reduction of echo amplitude from small flaws. While there exist analytical formulae to determine the optimum frequency, in practice it will be specified for a technician in the written procedure for each test. The transducers have their sensitive frequencies marked on their housing, or in some cases they will be color coded. The technician selects a probe with its sensitive frequency equal to the frequency specified in the UT procedure.

The size of the probe is selected to satisfy requirements of beam divergence, flaw detection versus location, and scanning speed. The larger the beam, the more slowly it diverges, which is important in thicker samples. A very wide beam can be used to detect a flaw and a much smaller beam used to accurately localize it. The term usually applied to a wide type of probe is "paint brusn",

and a typical set of measurements for a paint-brush probe is 3 inches wide by ½ inch thick. See Figure 32-2-12 for a sketch of a paintbrush transducer.



(a) Normal contact transducer

(b) Paint brush transducer

Figure 32-2-12 Contact Transducers

Temperature selection is a rare issue for the nuclear QA technician. Normally, tests are run at room temperature or at least well within the temperature range of normal probes. If normal probes will not satisfy an inspection procedure because of temperature, then care must be taken to select a high temperature couplant to match the high temperature probe(s).

Couplants

Two factors are very important in selecting and using couplants. First, commercial couplants are available in regular or high temperature versions from most vendors. Most test situations permit use of regular versions, but where high temperature testing is performed, the high temperature version should be selected. Second, when a modular angle-beam probe is used, the interface between the transducer and the adaptor needs a couplant in addition to the couplant between the adaptor wedge and the material surface.

Calibration

Once the probe has been selected for the given procedure, the equipment must then be calibrated. This calibration allows the vendor and owner to achieve comparable results from similar tests, and provides a standard to be utilized in estimating flaw size.

Reference Blocks

Reference blocks are used to calibrate ultrasonic test equipment. Three blocks must meet the requirements of the specific code or standard which applies to the UT examination procedure. The calibration blocks may be fabricated from extensions or cutouts of the material to be examined or they may be standard blocks fabricated from acoustically equivalent material as that to be examined. In either case, the applicable code or standard specifies the characteristics of the calibration block. Applicable codes and standards include those sponsored by American Society of Mechanical Engineers (ASME), American Society for Testing and Materials (ASTM), International Institute of Welding (IIW), and American Welding Society (AWS).

All calibration blocks provide ultrasonic reflectors of known size and location. Calibration of the UT equipment is accomplished by adjusting and electric controls on the control unit to obtain proper display of the reflectors in the calibration block. Several types of calibration blocks are reviewed in subsequent paragraphs; later in this module, sample calibration procedures are described.

The ASTM standard reference blocks come in three types of sets: a distance/amplitude set, an area/amplitude set, and a mixed set combining both of the above sets.

The ASTM distance/amplitude blocks provide a standard or reference flaw of a specific size at several depths in

the test material. The flaws are flat-bottomed, drilled holes centered in the bottom of the blocks. All the blocks are two inches in diameter, and all the holes are three-quarters of an inch in depth. As illustrated in Figure 32-2-13(a) the hole diameter is fixed at one of three diameters and only the test metal distance varies among the blocks of a set. Thus, these blocks provide a constant size reflector at various, known test metal distances.

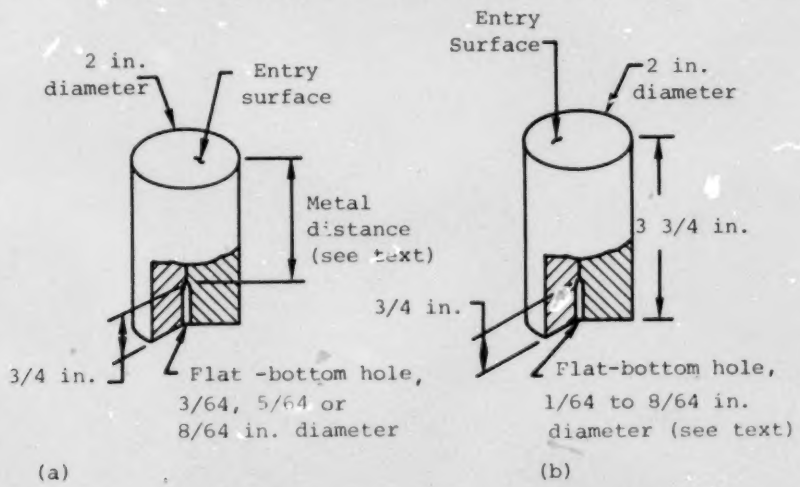


Figure 32-2-13 Standard reference blocks for use in straight-beam ultrasonic inspection: (a) distance-amplitude block and (b) area-amplitude block

The ASTM area/amplitude blocks provide a standard on reference depth of flaw, with the flaws being of various sizes or diameters. As illustrated in Figure 32-2-13(b), the flaws are, again, flat-bottomed holes drilled in the bottom of the blocks and centered. The blocks are, again, two inches in diameter with the bottom holes being three-quarters of an inch long. The metal distance is constant in this case, while the diameters of the hole of flaw differ. Thus, a set of area/amplitude blocks provides various, known flaw sizes at a fixed test metal distance.

Each of the area/amplitude and distance/amplitude blocks is identified by a five digit code number in the form of a single digit separated from four more digits by a dash. The first digit gives the diameter of the hole in sixty-fourths of an inch. The four remaining digits give the metal distance in hundredths of an inch. For example, a block marked 5-0600 has a flat bottomed hole diameter of five sixty-fourths (5/64) of an inch and a metal distance of 600 hundreths of an inch or six inches.

Because a flat-bottomed hole is a specular reflector, it will return an echo that is quite strong. Therefore, any equivalent strength echo from a real flaw will indicate a flaw cross-section larger than the flat-bottomed hole.

IIW -type blocks are used to calibrate equipment for either longitudinal or transverse (shear) examination and also to check the performance characteristics of an angle-beam search unit such as beam exit or index point and angle of refraction. IIW blocks come in both metric and English dimensions. Typical measurements are 12 in. x 4 in. x 1 in. Figure 32-2-14 shows a typical IIW standard block and an AWS miniature angle-beam block.

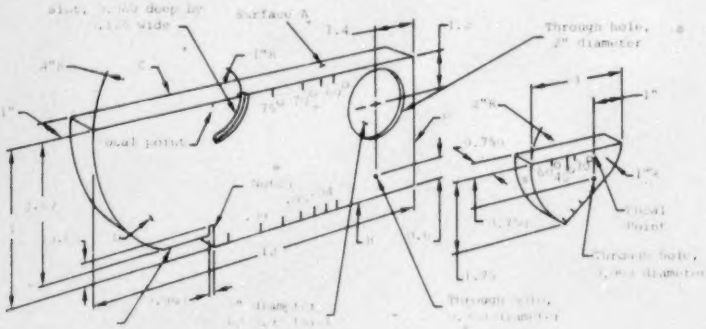


Figure 32-2-14 Two standard reference blocks used in ultrasonic inspection: (a) International Institute of Welding (IIW), type 1, block; (b) miniature angle-beam block

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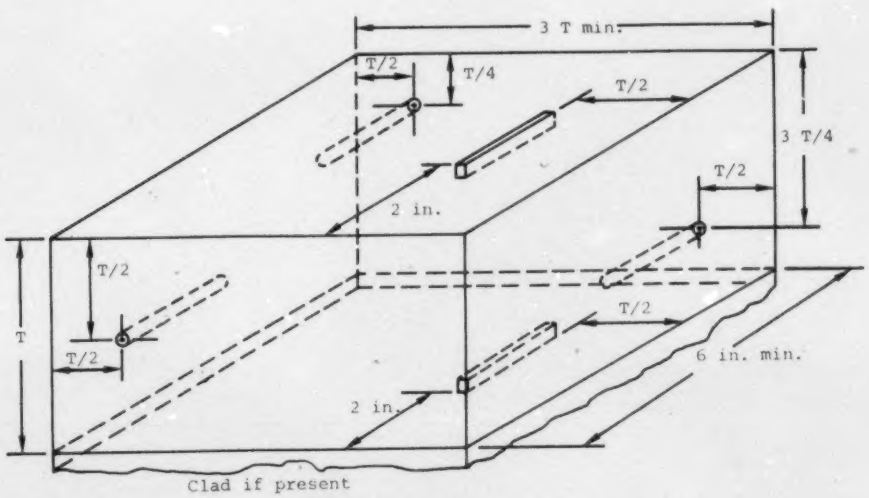
The ASME basic calibration block for ultrasonic examination of welds is illustrated in Figure 32-2-15. Side drilled holes are located at ¼T, ½T and 3/4T depths where T equals thickness of the block. Block thickness is equal or close to weld metal thickness as indicated by Figure 32-2-15. Drilled hole diameter is based on weld metal thickness range. Notches are machined to serve as a reflector which simulates flow on the inside surface of the weld.



Weld Thickness(t)	Basic Calibration Block Thickness(T)	Hole Diameter	Notch Size:
1 in. or Less	3/4 in. or t	3/32 in.	Width = 1/8 in. to 1/4 in.
Over 1 in. through 2 in.	1-1/2 in. or t	1/8 in.	
Over 2 in. through 4 in.	3 in. or t	3/16 in.	Depth = 2% T
Over 4 in. through 6 in.	5 in. or t	1/4 in.	
Over 6 in. through 8 in.	7 in. or t	5/16 in.	Length = 2 in. min.
Over 8 in. through 10 in.	9 in. or t	3/8 in.	

Figure 32-2-15 ASME Basic Calibration Block

Test Equipment Calibration

Ultrasonic test equipment is calibrated as a complete system. That is, the control unit, search unit, and cables form the test systems which is calibrated. Typically, three calibrations are required: (1) linearity, (2) sweep range calibration, and (3) distance amplitude. The Procedures section of this module gives specific procedures for performing these calibrations.

Linearity calibration determines the faithfulness of amplitude display on the CRT against either sensitivity (gain) settings or flow sizes. For example, if the sensitivity setting is changed to double the gain, the displayed pulse height should double. Likewise, a flaw signal twice as strong as another flaw signal should give a pulse height twice the amplitude of the other. The ASTM area/amplitude blocks provide a means of determining system linearity. It is recalled that the variable in these blocks is the diameter of the flat bottomed holes. Using the straight beam technique, the displayed pulse height should correlate with cross-sectional area of the holes. The plot of Figure 32-2-16 characterizes system linearity and a given sensitivity setting.

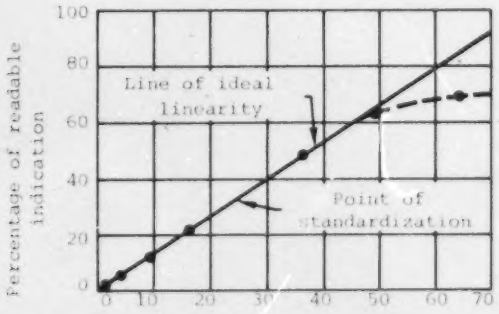


Figure 32-2-16 Typical area-amplitude response curve from test blocks

Sweep range calibration establishes the relationship between position of the test pulse along the sweep line and the depth of the reflector (flaw) in the test piece. The ASTM distance/amplitude blocks provide a means of sweep range calibration with straight beam technique. It is recalled that the only variable of the distance/amplitude calibration blocks is the test metal distance. As illustrated in Figure 32-2-17, the sweep range calibration using Delay and Range controls correlates the location of the pulse on the sweep line with the depth of the reflector in the test piece.

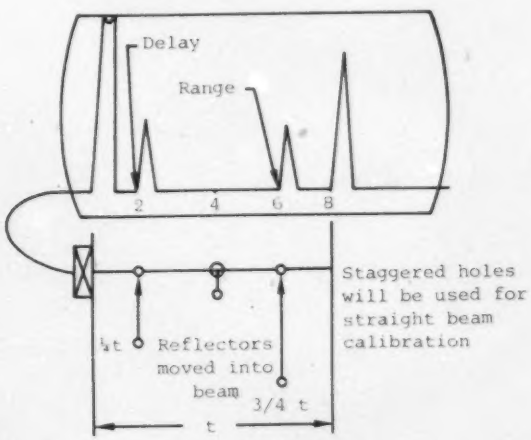


Figure 32-2-17 Beam Calibration

The electronic circuits of UT units provide a "time window" for the receive mode which is synchronized with the transmit mode. Only echos received during the "time window" are displayed on the CRT. The Delay control adjusts the real-time relationship between the time window and the instant of pulse transmission. With the CRT sweep starting coincident with pulse transmission, adjustment of Delay varies the location along the sweep of a pulse from a given reflector. With the search unit positioned to MAXIMIZE response from a

reflector at a test metal distance corresponding to ¼ thickness of material to be examined, Delay is adjusted to position the pulse on the sweep, for example at line 2. The Range control adjusts the duration of the "time window". Thus, Range adjusts the relative sweep position between pulses from reflectors at different depths. With the search unit positioned to maximize reponse from a reflector at a test metal distance corresponding to 3/4 thickness of material to be examined, Range is adjusted to position the pulse on the sweep, for example, at line 6. Accordingly, Delay establishes sweep position of the ¼t reflector at line 2 and Range establishes sweep position of the 3/4t reflector at line 6 in this discussion. With this relationship, sweep line 4 represents ½t and sweep line 8 represents t where t equals material thickness. It is noted that Delay and Range controls interact somewhat, and sweep range calibration requires repeating the adjustments at ¼t and 3/4t two or more times.

Distance amplitude calibration correlates the displayed pulse height with the depth of a constant size reflector. Dependent on such factors as beam divergence and wave attenuation, a given size reflector gives different heights of displayed pulses for different depths of the reflector. The ASME block using side drilled holes or the ASTM distance/amplitude blocks provide means of distance amplitude calibration. With the Sensitivity control unchanged, the pulse heights from a given size reflector is plotted against depth of the reflector (test metal distance). A curve similar to that in Figure 32-2-18 is obtained. A distance amplitude curve (DAC) for test applications is drawn on the CRT screen by connecting the peaks of the pulses from ¼t, ½t, and 3/4t reflectors of the calibrated blocks.

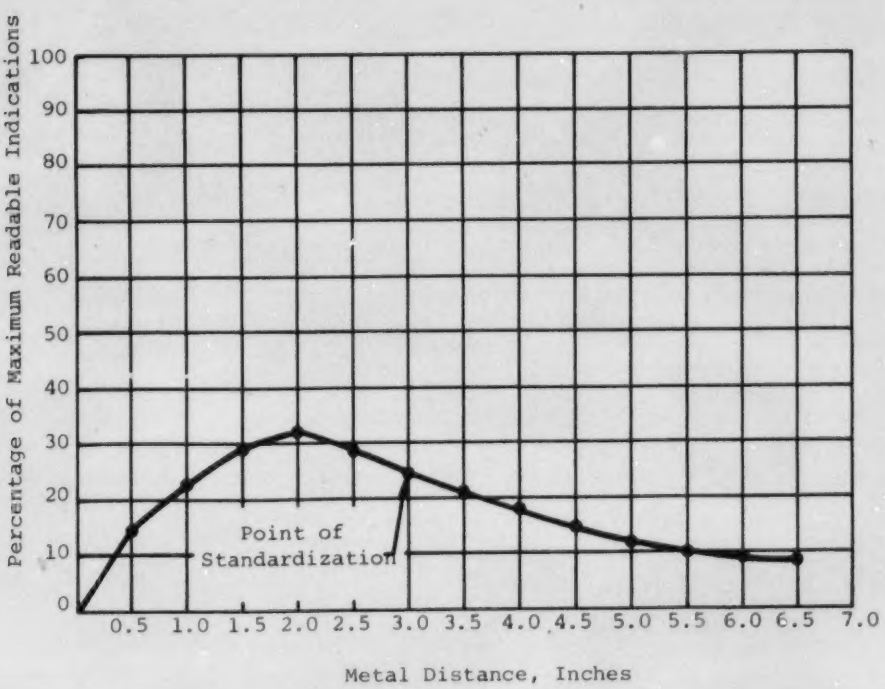


Figure 32-2-18 Typical Distance/Amplitude Response Curve

Flaw Detection

The minimum detectable flaw size depends on the wavelength (λ) being used for the test as given by:

$$r \geq \lambda \qquad \text{Equation 32-2-2}$$

Where:

r = the flaw radius, or one-half its diameter

Equation 32-2-2 indicates that for a flaw to be detectable, it must be at least one-half of a wavelength in diameter. This allows the selection of an appropriate frequency by using:

$$f = \frac{c}{(\frac{\lambda}{2})}$$ Equation 32-2-3

Where:

f = test frequency

c = acoustical velocity

λ = wave length

Given a metal with a velocity of sound equal to approximately 6000 $\frac{m}{sec}$, the following table lists some corresponding flaw diameters and minimum frequencies:

Table 32-2-1

Minimum Frequency Versus Flaw Size

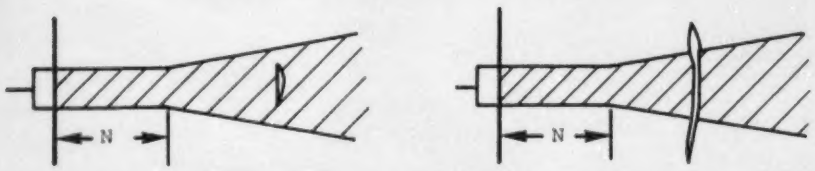
diameter (mm)	λ (mm)	f (MH_z)
0.5	1	6
1	2	2
2	4	1.5
4	8	0.75
6	12	0.5

It should be recalled that the orientation of a discontinuity affects its reflective ability and its echo strength. However, the question of detectability is essentially one of the interaction between a wave and a reflector.

FLAW POSITION, SIZE, AND SHAPE FOR STRAIGHT BEAM TESTING

In straight beam testing, the determination of flaw position, size, and shape is quite simple and to some extent has already been discussed in this module. For a straight beam, the depth of a flaw is read directly off the A-scan display. For position in the plane parallel to the surface, as a C-scan gives, the probe merely has to be maneuvered until the point or region of maximum indication is located. This is simple for a small target but somewhat harder for a large target.

The definition of a small target or flaw is that it is smaller than the ultrasonic beam at its depth. A large target is one that is larger than the ultrasonic beam at its depth. This is illustrated in Figure 32-2-19.



(a) Small Target (b) Large Target

Figure 32-2-19 Target Size N stands for near field, the remainder is far field.

Flaw shape and size can usually be determined for a large flaw by tracing the outline of the flaw. One technique for outlining a large flaw is illustrated in Figure 32-2-20. For laminations, multiple back wall echoes from an unflawed section are presented on the CRT screen as in Figure 32-2-20(a). The search unit is then maneuvered to

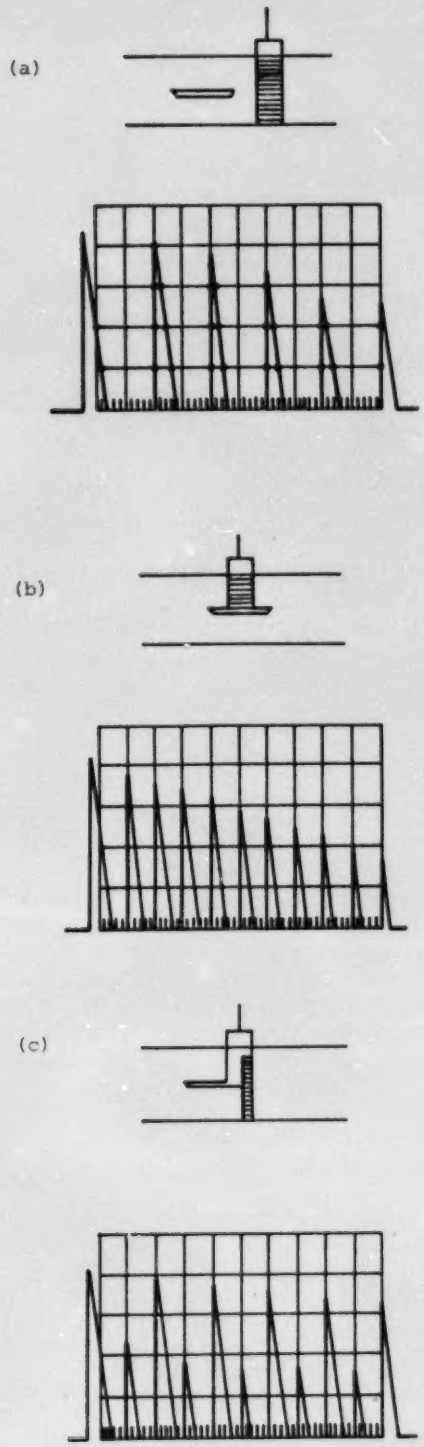


Figure 32-2-20 Flaw Indications

Special Test Problems

Material properties which determine the ability to ultrasonically test a metallic sample are acoustic velocity and grain size. These properties are strongly affected by the material's heat treatment and less strongly by the material's alloy composition. In point of fact, the variations in acoustic velocity of different steels are quite small, on the order of or less than 5%. For survey tests or "rough- and dirty" quick scans, variations of that size can be neglected for tests using longitudinal waves. For angle beam tests, however, a 5% error in sample acoustic velocity could imply an approximate error of 3° at a 45° test angle in the sample material. Therefore, the calibration blocks should be of exactly the same material as the test sample. To eliminate as much of the grain-size problem as possible, the calibration block should have received exactly the same heat treatment as the test sample.

Special grain size problems occur in various high alloy steels. If coarse grains form, as is common in high alloy steels, large variations in scattering, and hence attenuation may occur within the test material. On the other hand, some stainless steel alloys have extremely low attenuation factors, which can cause spurious echoes. These spurious echoes, are actually late multiple echoes. They can be avoided by reducing the pulse repetition rate of the equipment.

A most critical problem for nuclear ultrasonic testing is the attenuation problem in austenitic weld material. This attenuation decreases the reliability of an ultrasonic examination of a weld, and may even preclude a complete examination of the weld. Attenuation in austenitic welds is primarily due to large columnar grains, called dendrites, formed by the slow, directional cooling during the weld process. Because these dendrites exhibit large changes in

acoustic impedance at their boundaries, a substantial portion of a test beam can be reflected at these grain boundaries. This means that small defects are less likely to be located in an austenitic weld than in a ferritic weld.

The most important means of controlling the problem of attenuation is to carefully control the welding process. If the grains are oriented correctly, attentuation can be minimized. This, however, is of no use to an NDE technician once the weld is complete. The only thing to be done then is to alter the UT technique.

There are three techniques which show promise, but which have not yet been approved for nuclear use by ASME and NRC. These techniques include pitch-catch transducers, focusing probes, short pulses, and longitudinal waves as opposed to single, non-focusing probes, normal length pulses, and transverse waves. If equipment availability precludes these test techniques, test frequency selection is about the only method of reducing attenuation. Since resolution decreases with frequency, the best selection of test frequency is approximately 1 MH_z. While this frequency is not ideal for either attenuation or resolution, it represents a good compromise.

Other particular problems for nuclear QA/QC technicians concern uranium, zirconium, hafnium, and zircalloy tubes. Plates and rods of metallic uranium are normally tested by the immersed transmission method at 1 to 2 MH_z. Hafnium can also be immersion tested to 5 MH_z , while ingot form. Zirconium ingots are most frequently contact tested at 1 MH_z by the pitch-catch pulse echo technique.

Zircalloy tubes, used for fuel cladding, are immersion tested with pitch-catch transducers. They are generally guided past the transducers, which remain fixed, by a revolving feed mechanism. This method is used by vendors and utilities for manufacturing checks and acceptance tests.

Special Test Problems in Non-Metals

Very dense burnt porcelians used as insulators are ultrasonically tested during manufacture. Glass is not, in practice, tested using UT. Detectable faults include cracks, shrinkages, and inclusions. Care should be taken to account for differences in acoustic velocity between nominally similar porcelains depending on the supplier.

Plastics include a very wide range of material properties, from lucite to teflon to polyethelene. This range of materials demonstrates great variability in absorption of ultrasound. Frequencies of interest in testing plastics are in the low megahertz range. Wear on metal faced probes used to test plastics may be disregarded. Pitch-catch transducers are preferable, especially in thin samples to eliminate dead zones. The immersion technique offers a good acoustic match between the plastic and water, better than with metal, which means less loss due to interface reflections. Transverse waves do not propagate well in plastic, necessitating the use of longitudinal waves.

Concrete may only be ultrasonically tested at frequencies of 100 KH_z or less due to the inheterogentiy of the material. The largest problem with this frequency range is the lack of resolution due to poor beam directionality. Barium titanate is the most commonly used transducer material, although various types of magnetostrictive receivers are sometimes used. An evaluation of the acceptability of concrete can usually be made by measuring the longitudinal velocity of sound in the concrete.

Many other special test situations occur in UT work but are of little interest to the nuclear QA/QC technician, for example, these include the measurments of fat and meat thickness on pigs.

EXERCISES

Determining Position, Shape, and Level

In addition to the testing and measuring of materials, ultrasound may be used as a pure sounding method. It can be used to locate almost any change in density, such as the presence of air bubbles or foreign matter in a pipe or other container, to determine water level in a tank, or to locate accurately pieces welded to the back side of a plate.

1. Sketch a 45^{o} angle beam search pattern for the test specimen illustrated in Figure 32-2-23.

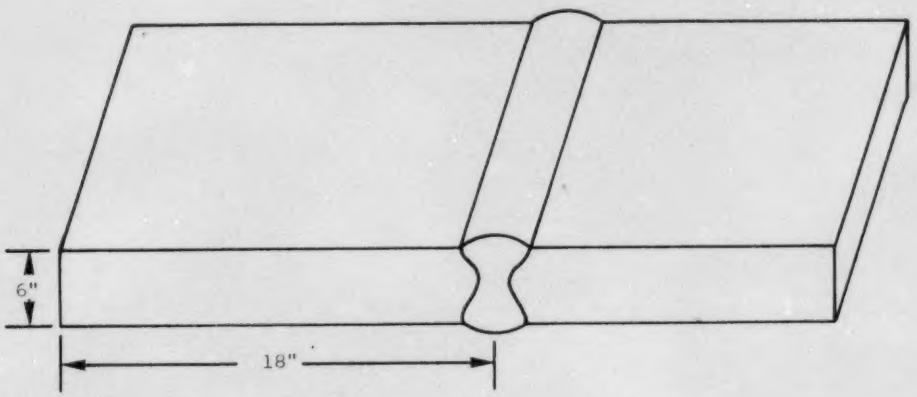


Figure 32-2-23 Welded Specimen

2. Prepare for the Procedures of this module by studying the ultrasonic test equipment manufacturer's technical manual and visually observing the equipment, probes, and cables.

MATERIALS

The following materials are required to support this module:

1. Portable ultrasonic pulse-echo test unit, with 2.25 MH_z single and dual transducers and cables.
2. Couplants (30 wt. oil)
3. Grease pencils
4. ASTM distance-amplitude calibration blocks
5. ASTM area-amplitude calibration blocks
6. IIW standard reference block
7. Assorted material specimens

PROCEDURES

1. Construct an area-amplitude curve for a contact, pulse echo test system using the longitudinal wave technique:
   a. Energize the test unit and allow warm up time in accordance with the manufacturer's technical manual.
   b. Select a number 5 area-amplitude reference block.
   c. Select 2.25 MH_z test frequency.
   d. Place couplant and the search unit on the top surface of the block, slightly off center.
   e. Manipulate the probe until a maximum bottom-hole response is obtained. (NOTE: If not preset, the Position controls may have to be adjusted to bring the echo-pulse on screen.)
   f. Adjust the Sensitivity until the CRT pulse height of the bottom-hole indication is 30% to 35% of the maximum obtainable on the CRT screen.

g. Replace the number 5 block with the other area-amplitude blocks available.

h. Record each indication's height or amplitude using the same sensitivity setting established with the number 5 block.

i. Plot the amplitudes as a percentage of maximum pulse height, versus the square of the block number, on Data Table 32-2-1.

j. Draw a straight line through origin and the data point for the number 5 block's amplitude. This is the line of ideal linearity. Significant deviations from this line are used to correct readings on actual flaws at that distance.

2. Construct a distance-amplitude curve for contact, pulse echo system using longitudinal wave technique:

a. Energize the equipment and allow warm up time in accordance with manufacturer's technical manual.

b. Select a number of 5-0300 distance-amplitude reference block.

c. Place the couplant and the probe on the top surface of the block slight off center.

d. Select a 2.25 MH_z test frequency.

e. Manipulate the probe until a maximum bottom-hole response is obtained.

f. Adjust the gain until the CRT pulse height of the bottom hole indication is approximately 25% of the maximum obtainable on the CRT screen.

g. Replace the No. 5-0300 block with the other distance amplitude blocks available.

h. Record each indication's height or amplitude using the gain setting established for the No. 5-0300 block.

i. Plot on Data Table 32-2-2 the amplitudes as a percentage of maximum pulse height versus the metal distance for each block. The resulting curve should be similar to Figure 32-2-18, with pulse height increasing in distance in the near field, and decreasing with distance in the far field.

3. Determine beam angle and beam spread using an IIW Standard Reference Block:

a. Energize the test system and allow warmup time in accordance with manufacturer's technical manual.

b. Select 2.25 MH_z test frequency.

c. Select or assemble dual unit search probe and 45% weld.

d. Place couplant and search unit on surface A of the reference block at the focal point scribe line and such that the angle beam is directed toward the four inch radius.

e. Position the search unit to maximize the back wall reflection from the radius and scribe the search unit at the point corresponding with the focal point of the reference block. This marks the index point of the search unit.

f. Place couplant and search unit on surface B of the reference block such that the angle beam is directed toward the two inch diameter circular cutout.

g. Position search unit to maximize response from the two inch circle and read beam angle at the coincidence of the index point of the search unit and the inscribed angle scale adjacent surface B.

h. Position search unit either side of beam angle and note the angle at which the response from the two inch circle disappears. Calculate beam spread by subtracting these two angles.

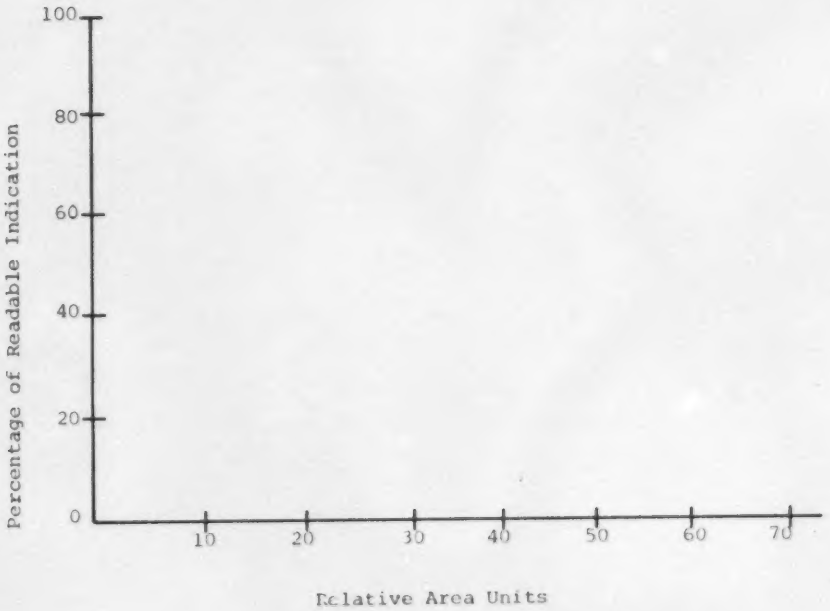
4. Ultrasonically test by longitudinal wave technique a material specimen provided by the instructor:
   a. Energize the test equipment and allow warmup time in accordance with the manufacturer's technical manual.
   b. Select 2.25 MH_z test frequency.
   c. Select three ASTM distance-amplitude calibration blocks having test metal distances of ¼t, ½t, and 3/4t where t equals thickness of the material to be examined.
   d. Perform sweep calibration by testing each block and adjusting Delay and Range such that the ¼t and 3/4t responses correspond to sweep lines 2 and 6 respectively. (See module subject matter for help.)
   e. Test the calibration block which gave the highest pulse while performing sweep calibration and with the response maximized, adjust Sensitivity to obtain a pulse height of 80% of full CRT screen height. Mark the peak of the response on the screen with a grease pencil.
   f. Test the two remaining reference blocks at the same sensitivity setting and mark the peaks on the screen with a grease pencil.
   g. Connect the three marks on the screen to form the DAC.
   h. With the attenutation switch, add 6 db gain (double the gain).
   i. Apply couplant to the test material and scan the material using parallel scanning paths with at least 10% overlap.
   j. Whenever indications are noted, maximize the response, return attenuator to original setting, record pulse

amplitude as either above or below DAC, and record flaw depth by noting position in sweep. Mark the location of the flaw on the test specimen by outlining the search unit.

DATA TABLE

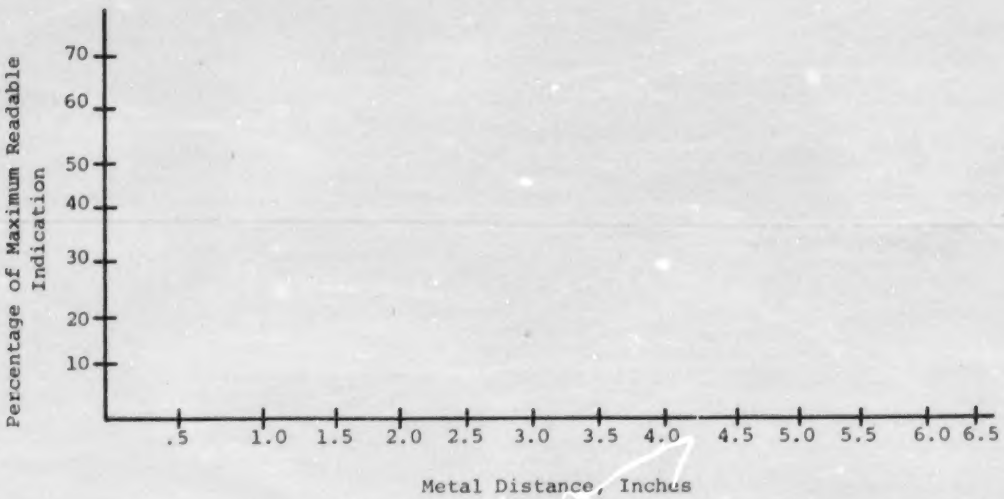
Data Table 32-2-1

Area-Amplitude Calibration



Data Table 32-2-2

Distance Amplitude Curve



REFERENCE MATERIALS

ASME, Boiler and Pressure Vessel Code, Section V, Nondestructive Examination, The American Society of Mechanical Engineers.

General Dynamics, Convair Division; Classroom Training Handbook for Nondestructive Testing: Ultrasonic Testing; General Dynamics; San Diego, California; 1967.

Goldberg, Barry B., et al; Diagnostic Uses of Ultrasound; Grune and Stratton; New York, 1975.

Hueter, T.F. and Bolt, R.H.; Sonics, 5th ed.; ASNT; Columbia, Ohio; 1966.

Krautkrämer, J & H; Ultrasonic Testing of Materials; Springer-Verlag; New York; 1969.

Ward, Raymond, et al; Metals Handbook, 8th Edition, Volume 11, "Nondestructive Inspection and Quality Control;" American Society for Metals; Metals Park, Ohio, 1976.

TEST

A. Multiple Choice:

Circle the most correct answer following each question which follows:

1. The search unit used in immersion testing is frequently varied in position and orientation to change the angle of refraction in the test piece. This is referred to as:
   (a) angulation (c) attenuation
   (b) dispersion (d) calibration

2. The preferred ultrasonic testing method for detecting flaws oriented parallel to the surfaces of a plate is:
   (a) angle-beam contact method with surface waves.
   (b) straight-beam contact method with longitudinal waves.
   (c) immersion test using surface waves.
   (d) angle beam contact method with transverse waves.

3. When inspecting aluminum by the immersion method using water for a couplant, the following information is known: velocity of sound in water (1.49 km/sec) and aluminum (6.30 km/sec), and the angle of incidence equal 5°. The angle of refraction for longitudinal waves is approximately:
   (a) 16° (c) 22°
   (b) 18° (d) 26°

4. In general, _____ waves will travel around gradual curves with little or no reflection from the curves.
   (a) transverse
   (b) surface
   (c) torsional
   (d) longitudinal

5. When using two separate probes, one functioning as a transmitter, the other as a receiver, the most efficient combination would be:
   (a) a quartz transmitter and barium titanate receiver
   (b) a barium titanate transmitter and a lithium sulfate receiver
   (c) a lithium sulfate transmitter and a barium titanate receiver
   (d) a barium titanate transmitter and quartz receiver

6. In immersion testing, the water distance between the search unit and the test piece should be:
   (a) as small as possible
   (b) the same as the thickness of the test piece
   (c) the same as the water distance used during calibration
   (d) as great as possible.

7. Defects near the entry surface cannot always be detected due to:
   (a) far field effect
   (b) attenuation
   (c) refraction
   (d) test system recovery time

8. Angle-beam testing is most likely to miss:
   (a) cracks perpendicular to the sound wave
   (b) cracks parallel to the front surface
   (c) randomly oriented inclusions
   (d) a series of small discontinuities

9. Under most circumstances, which of the following frequencies would result in the best resolving power?
   (a) 0.5 MH_z
   (b) 1.0 MH_z
   (c) 3.0 MH_z
   (d) 5.0 MH_z

10. Metal blocks containing one or more drilled holes to simulate discontinuities are called:
   (a) scrubbers
   (b) reference blocks
   (c) crystal collimators
   (d) angulators

11. In general, transverse or shear waves are more sensitive to small discontinuities than longitudinal waves for a given frequency and in a given material because:
   (a) The wavelength of transverse waves is shorter than the wavelength of longitudinal waves.
   (b) Transverse waves are less easily dispersed than longitudinal waves.
   (c) Transverse waves travel faster than longitudinal waves.
   (d) The wavelength of transverse waves is longer than the wavelength of longitudinal waves.

12. Which ultrasonic test frequency would most reasonably provide the best penetration of a 12-inch thick specimen of coarse grained steel?

(a) 5 MH_z
(b) 1 MH_z
(c) 10 MH_z
(d) 2.25 MH_z

13. Generally, the best test method for detecting discontinuities oriented along the fusion zone in a weld is:

(a) an angle beam contact method for surface waves
(b) a contact method using straight longitudinal waves
(c) an immersion test using surface waves
(d) an angle beam method using shear waves

14. Which of the following is <u>not</u> an advantage of contact probes adapted with lucite shoes?

(a) little crystal wear
(b) adaptation to curved surfaces
(c) increased sensitivity
(d) varied entry angles for test beam

15. The angle of reflection of an ultrasonic beam at an aluminum-water interface is _____ the angle of incidence.

(a) ½
(b) 4 times
(c) equal to
(d) .256 times

16. A weld inspection ruler or calculator is used in _____ testing.
    (a) straight beam pulse echo
    (b) angle beam pulse echo
    (c) straight beam resonance
    (d) straight beam transmission

17. The DAC curve provides a means of:
    (a) determining acceptance of flow size
    (b) calibrating for linearity
    (c) locating the depth of flows
    (d) scribing the index point

B. Short Answer, Problem and Essay Questions:

Answer the following questions as indicated:

1. State the physical property of lucite that makes it a good choice of material in an angle-beam wedge adaptor in a probe and briefly explain why.

2. Differentiate between squirter and bubbler techniques.

3. What is the identification code number of an ASTM standard reference block with a height of 4 3/4 in. and a hole diameter of 7/64 in.

4. What minimum frequency must one use to detect a 3 mm diameter flaw in metal with $C_l = 6000 \frac{m}{sec}$?

5. In order to measure, the thickness of a sample, the acoustic _____ of the sample must be known.

6. A large columnar grain, frequently found in austenitic welds, is called a _____.

7. A test frequency of _____ is best for examination of austenitic weld material.

8. _____ waves should be used in examining plastics.